Tunable Continuous-Wave Fiber Optical Parametric Oscillator with 1-W Output Power

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Abstract: We report on a CW fiber OPO, whose output wavelength can be tuned over the 1463-1674nm range, by means of a tunable intracavity filter. Over 1W of output power can be extracted at long wavelengths.

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1. Introduction.

Fiber optical parametric oscillators (OPOs) have been investigated in recent years, as they have the potential for providing tunable radiation in regions of the optical spectrum not well covered by the main laser systems [1]. Most of the work has been performed with pulsed pumps, which can provide high peak powers, and hence lead to short OPOs that can be made from relatively lossy fibers, such as microstructured fibers. Powers obtainable with continuous-wave (CW) pumps are lower, and so larger lengths of low-loss fibers are required. This limits performance, compared to pulsed pumps, and as a result few CW fiber OPOs have been investigated [2,3,4,5,6]. To date the emphasis has been on obtaining large tuning ranges. Since this is helped by reducing all losses, including those due to output coupling, all demonstrations to date have yielded relatively low output powers and conversion efficiencies. For example the OPO of Ref. [6], driven by a 5-W pump, only had a maximum output power of about 125 mW.

Here we report on a tunable fiber OPO with a 3 dB output coupling fraction, suitable for extracting high powers from the resonator, with high efficiency: specifically we have obtained over 1 W of output power near 1670 nm, for 2 W of pump power incident on the resonator, with a maximum external conversion efficiency of 61%. Also, with the same output coupler, the output wavelength could be tuned in the 1463-1674 nm range, covering the S- and XL-band, not available with erbium-doped fiber amplifiers (EDFAs) and lasers (EDFLs).

2. Experimental Setup

The experimental setup is shown in Fig. 1. A tunable laser source was used as pump at 1561.5 nm. The pump light was then phase-modulated by a 10 Gb/s pseudo-random binary sequence (PRBS) source, to suppress the stimulated Brillouin scattering (SBS). After this a 3-W EDFA was used in order to boost the pump power, followed by a 1 nm bandwidth filter to filter out the amplified spontaneous emission (ASE). Then a wideband WDM coupler (1480/1550) was used to couple with low loss pump and intracavity signal into a 340-m long highly non-linear fiber (HNLF). The HNLF had nonlinearity coefficient γ = 15 $W^{-1}km^{-1}$, and zero dispersion wavelength (ZDW) at 1560 nm. After it a 20-dB coupler was used to measure the SBS power, and the input power to the HNLF, which was 33 dBm. After the HNLF a 3-dB coupler was used to couple half of the power out of the resonator, and to couple the other half back into the resonator. Then in the resonator a narrow tunable bandpass filter (TBPF) was used, which had an insertion loss of 5 dB, and a tuning range extending from 1460 to 1575 nm. Total cavity loss was measured to be 9.8 dB.

3. Results.

To get the OPO to oscillate, the OPA gain for the signal must be higher than the intracavity losses; this could readily be achieved with the pump power injected into the resonator. Figure 2 shows OPO output spectra obtained for various settings of the intracavity tunable filter. This shows that OPO lasing could be obtained from 1463 to 1674 nm, which corresponds to a 211-nm wide tuning range. Also, our OPO output spectra were narrower than in [6], as we used a very narrow intracavity filter (0.01 nm bandwidth).

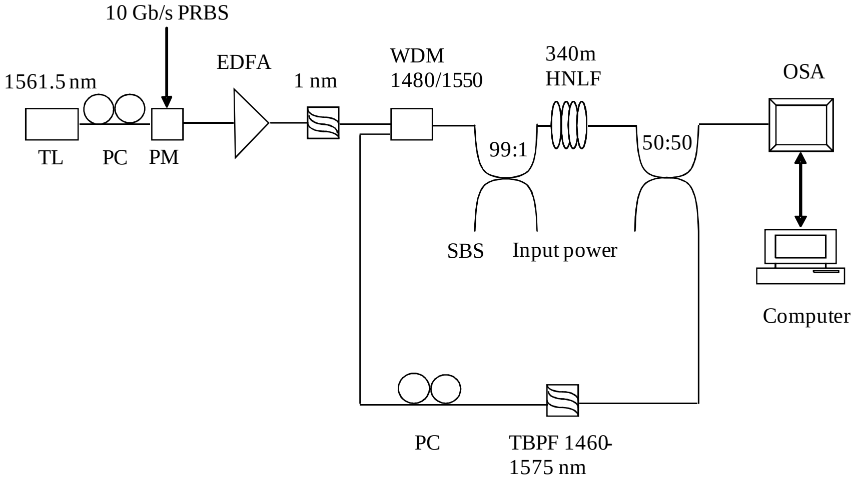

Figure 1. Experimental setup of the CW Fiber OPO.

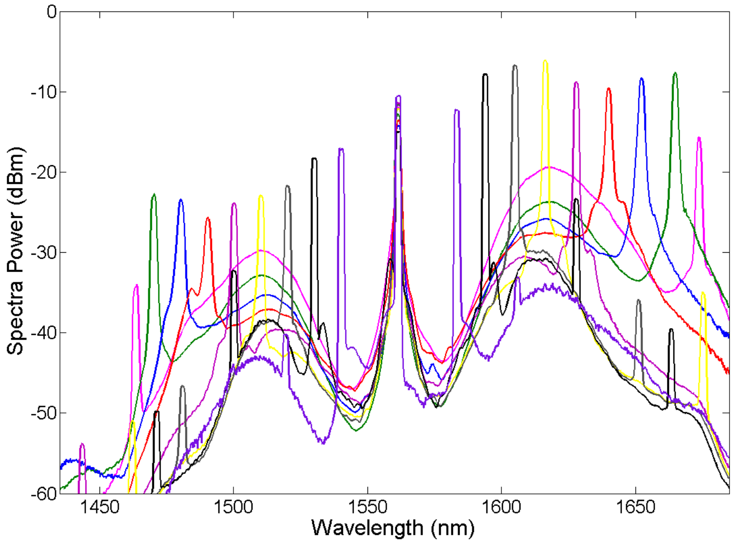

Figure 2. OPO ouput spectra obtained for different settings of the bandpass filter.

The peak output power variation with signal wavelength is shown in Fig. 3. This shows an output signal power in the vicinity of 1 W from 1600-1670 nm. Peak powers on the Stokes side are as much as 7.1 dB higher than the pump output power, which indicates strong pump depletion, and hence high conversion efficiency. This shows that we have a much higher conversion efficiency than achieved in previous work [4,6]. We defined external conversion efficiency as the ratio of output signal power and input pump power launched into the HNLF. Fig. 3(b) shows the external conversion efficiency variation with wavelength, which reaches as high as 61 %. By contrast, the external conversion efficiency in the most recent work, Ref. 6, is only 2.5 %. To our knowledge this is the best external conversion efficiency achieved to date with a fiber OPA, together with such a large tuning range. So overall we achieved a tuning range comparable to the maximum achieved so far [6], but with considerably higher output power and external conversion efficiency.

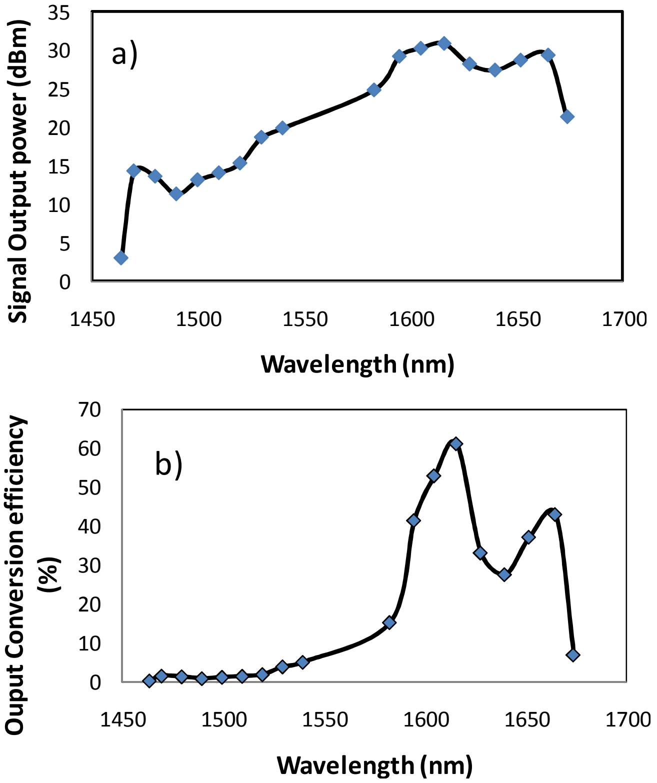

Figure 3. (a) OPO output power versus output wavelength. (b) External conversion efficiency versus output wavelength.

4. Conclusion.

We have shown that by using a 3-dB output coupler for extracting power from a fiber OPO, we can obtain over 1-W output power at long wavelengths (1600-1670 nm), and 61 % peak external conversion efficiency. This OPO also exhibits a tuning range in excess of 200 nm. This combination of high output power and large tuning range in a CW source could be attractive for a number of applications such as Raman pumping for optical communication, eye-safe atmospheric optical communication, remote sensing, etc.

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5. References

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